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14. ABSTRACT The objective of our study is to produce a computer-based Advanced Prosthetic Gait Training Tool to aid in the training of clinicians at military treatment facilities providing care for wounded service members. In Phase I of the effort, significant work was completed at the University of Iowa Center for Computer-Aided Design (CCAD), the University of Iowa Orthopedic Gait Analysis Laboratory (OGAL), and the Military Performance Laboratory (MPL). A representative set of motion capture sequences was provided by MPL to CCAD and OGAL. CCAD's work focused on imposing these sequences on the Santos™ digital human avatar. An initial user interface for the training application was also developed. During the current phase, the user interface was significantly enhanced. The new interface is easy highly intuitive reducing the learning time for a new clinician. In addition, the software is modular and expandable in terms of additional clinical conditions and corresponding training and evaluation material. Based on initial feedback, various mechanisms of training clinicians were tested by the team at OGAL and VSR. Finally, motion capture data transfer protocol was tested between the teams at OGAL and VSR. The team has a final version of software that is usable, but can be improved by enhancing the motion capture and data preparation processes.					
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Advanced Prosthetic Gait Training Tool

Introduction

The objective of our study is to produce a computer-based Advanced Prosthetic Gait Training Tool (APGTT) to aid in professional development for clinicians and prosthetists at military treatment facilities providing care for wounded service members. The effort will ultimately provide practitioners at all clinics and hospitals with access to advanced, computer-based gait analysis tools that are currently available at only a few state-of-the-art gait laboratories. The tool will aid in the training of service providers, ultimately improving the level of care they provide to wounded veterans.



Figure 1 - Use of Santos and motion capture profiles from the Military Performance Lab at the Center for the Intrepid to develop Advanced Prosthetic Gait Training Tool.

Due to the wide variety of injuries suffered by military personnel and the wide range of medical interventions employed to improve the standard of living for patients, it is very challenging to expose medical practitioners to a comprehensive set of human subjects to support their training in gait analysis. Under this effort, an extensive set of archived motion-capture data representing gait patterns for wounded service members with varying challenges will be harvested from the Military Performance Laboratory at the Center for the Intrepid at Brooke Army Medical Center in San Antonio to develop a tool for training medical practitioners and prosthetic designers.

To ensure confidentiality for service members, gait patterns will be imposed on Santos. APGTT then allows for the repeated virtual playback of motion sequences that can be viewed from any angle. The trainees will then enter their assessments of observed gait deviations, which will be scored against standard measures prepared by experts in the field. Based on the accuracy of the trainees' responses, the system will provide immediate remediation. This will provide a comprehensive training experience, allowing practitioners to benefit from a broad array of patient data previously collected by the US Army, thus bridging a critical gap in current medical training practices. The system will be developed to accommodate additional sequences captured over time, thus offering an extensible, distributable, and sustainable training library.

The three main components of APGTT are as follows:

- 1) **Motion capture:** Data were obtained from the Orthopedic Gait Analysis Lab (OGAL) at the University of Iowa, using different marker protocols, for proof of concept in translating the new marker protocol of the gait data to the Santos model in a consistent manner. Subsequently, the vast amount of data already available at the Military Performance Lab at the Center for the Intrepid will be used to train students for various conditions. The data has been de-identified and classified based on the clinical condition of the patients to aid in the development of the training tool.
- 2) **Gait deviation ratings:** Using these gait profiles, gait experts at University of Iowa Hospitals and Clinics developed an assessment to examine general issues related to the ability of the user to observe differences in the walking patterns. There is one module to assess visual sensitivity and two modules to train individuals to distinguish gait deviations (trunk motion and lower-limb motion). Each of these modules help trainers improve their ability to observe differences in gait patterns and thus aid in selecting the best medical intervention for the observed condition.
- 3) **Prosthetic gait training software/interface:** The gait modules have been included in an intuitive, user-friendly interface to train the clinical students. The training software has been developed using modular architecture so that new motion profiles can be easily incorporated in the training procedure along with corresponding gait modules. The software includes pre-test and post-test sessions along with the ability to save and communicate the results of these tests to study the effectiveness of the curriculum.

Motion Capture Investigation:

During the previous year, motion capture data were obtained from the Gait Lab, using a set of marker protocols, for proof of concept in translating the new marker-protocol of the gait data to the Santos model in a consistent manner. Based on the provided gait data, some joint center profiles were provided and others were generated inside Virtual 3D using the new marker protocol. While the resulting motion of Santos based on these joint center profiles after processing were promising, some challenges were encountered. During this year, most of the work focused on addressing these challenges. As a recap of last year's work, below is the methodology outline and the marker protocol.

METHODOLOGY OUTLINE

1. Human gait test data under different protocols were obtained for a trans-tibial amputee. The following steps were taken to translate the data from motion capture to the Santos model (see Figure 2).
2. A Visual 3D model was used at the Gait Lab to generate the required markers and to estimate some joint-center locations of the different body segments (Figure 2a).
3. Additional Visual 3D virtual points were created at the 3DBMRL lab and were exported for additional joint centers relative to the Santos skeleton (Figure 2b).
4. Link lengths between segments were calculated for input into the Santos skeleton (Figure 2c).
5. An in-house inverse kinematic software was used to predict joint angles of different segments, which were used subsequently as input motion file for Santos animation (Figure 2d).

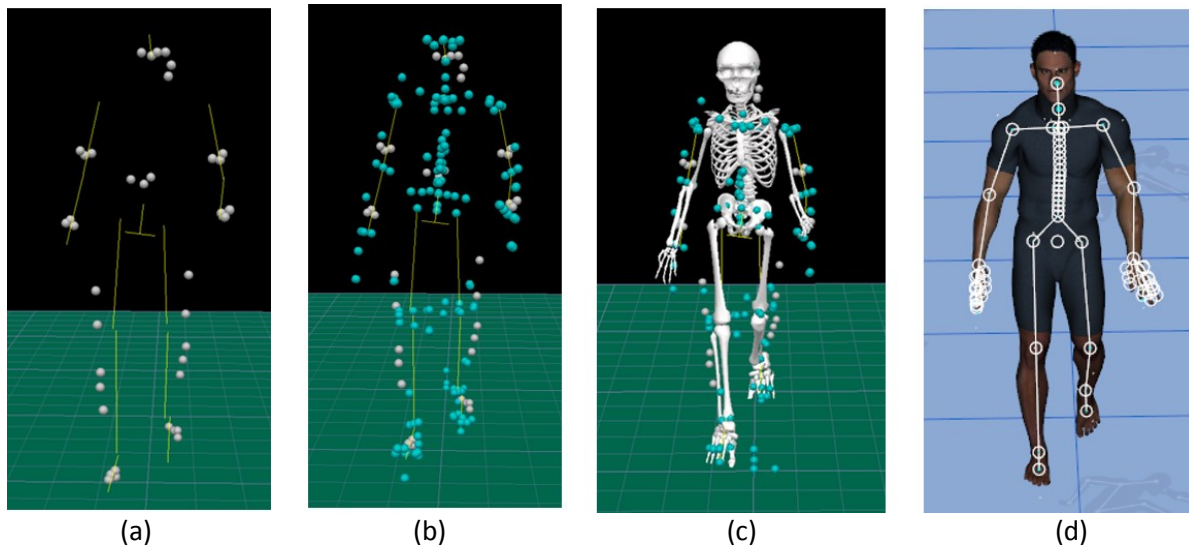


Figure 2 - The flow from motion-capture data collection to animation in Santos: (a) motion-capture markers only inside Virtual 3D, (b) landmarks created in the body based on motion-capture markers inside Virtual 3D, (c) skeleton added in Visual 3D model to calculate different segment lengths, and (d) joint centers exported to Santos for animation.

Table 1. Santos joint center locations required to recreate motion capture data from in-house predictive dynamics optimization code

NAME	LOCATION
Spine1	Base of the spine near L5 spinous process
Spine2	Proportional distance up spine near T12 spinous process
Spine3	Proportional distance up spine near T10 spinous process
Spine4	Proportional distance up spine near T7 spinous process
Spine_Rigid	Intersection of spine and the point between the shoulder joints
LowNeck	Base of the neck near C7 spinous process
UpperNeck	Top of the neck near C1 spinous process
LCLAV, RCLAV	Approximately one-fourth distance between manubrium and acromion
LSHO, RSHO	Shoulder joint center, slightly inferior of acromion
LELB, RELB	Elbow joint center, between lateral and medial epicondyles of humerus
LWRST, RWRST	Wrist joint center, between radial process and ulnar styloid process
LFIN, RFIN	On index finger near 1 st metacarpal head
LHANDB, RHANDB	Distal end of middle phalange and used as end effector
Lhip, Rhip	Hip joint center, proportioned from RASIS, LASIS, RPSIS & LPSIS
LKNEE, RKNEE	Knee joint center, between lateral and medial condyles of femur
LANKLE, RANKLE	Ankle joint center, between lateral malleolus of fibula and medial malleolus of tibia
LTOE, RTOE	Between midpoint of 5 th metatarsal and head of 1 st metatarsal and used as end effector
MidHead	Center of head rotation at the C0 occipital joint
Head_Right	Outside point of head directly lateral of MidHead
RBAK	Medial border of the scapula on the level of T3, approximately midpoint between T7 spinous process and right shoulder joint

Previous work had indicated some difficulties associated with transforming the motion-capture data between the human subjects and the Santos biomechanical model that may affect the way clinicians score the gait data when using Santos. It was expected that these difficulties would be associated with the differences between the human-body skeleton and the Santos biomechanical model in terms of anthropometry and shape. These differences would lead to difficulties matching the locations of the retro-reflected markers on the human body during the testing with the corresponding marker locations on Santos's skin, therefore, creating inaccuracies in predicting joint center locations, link lengths, and the resulting joint angles.

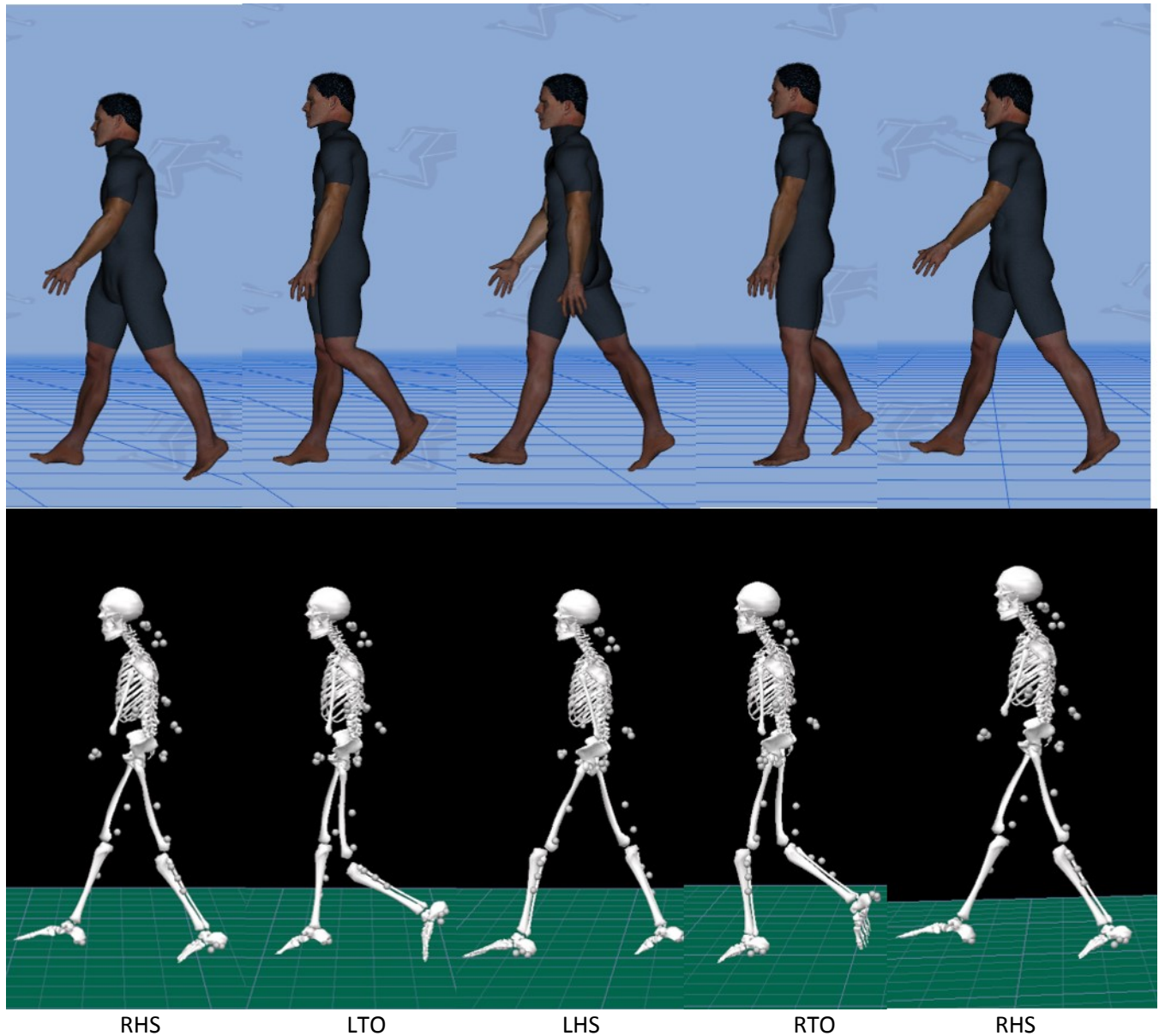


Figure 3 – Comparison of various frames of motion-capture data imposed on Santos and the real data in Visual 3D environment.

In this work, thirty-five motion-capture data files of four subjects were received from OGAL. The data were processed at VSR through Virtual 3D, Matlab, and finally Santos to calculate the resulting human joint angles during gait. The resulting motion data, in CSV formats, and animation videos were sent to OGAL to be used for further analysis in the ProGait program.

Due to issues outlined above, there were minor differences between the resulting motion in Santos and those coming from the human subjects tested at OGAL. Because these differences may create some uncertainties in scoring subjects' gait, the motion data were reprocessed in different ways to reduce these differences. Each reprocessing process was based on discussions between VSR and OGAL and

included reprocessing the data in both labs for the sake of finding any differences in the data processing or set-ups.

One main issue that was detected during the observation and discussions was the mismatch between the biomechanical models inside Virtual 3D at VSR and OGAL. As a result, we have been working on creating very similar models at VSR and OGAL. We have coordinated with OGAL to develop biomechanical models inside Virtual 3D that have good representation of the tested subjects. Additional work has been done to investigate different marker protocols on the human subject in order to achieve a good representation of the locations of the joint centers of the human segments. The marker protocols included using different numbers of markers at different locations on the human body.

After unifying the skeletal models inside Virtual 3D at VSR and OGAL, the next step was to deal with the mismatch between Santos's biomechanical skeleton and the models in Virtual 3D. One issue was to fix the height of the subjects and create a suitable representation of the link lengths inside Santos. While Santos has a generic biomechanical model that can be scaled to different sizes, it was found that the scaling process of this model should be done appropriately to avoid discrepancies between the different skeletal models. Figure 4a shows Santos with an inappropriate scaling in which the right knee showed less flexion than it was supposed to show. Figure 4b shows Santos with a more accurate knee flexion when scaling Santos to an appropriate height.

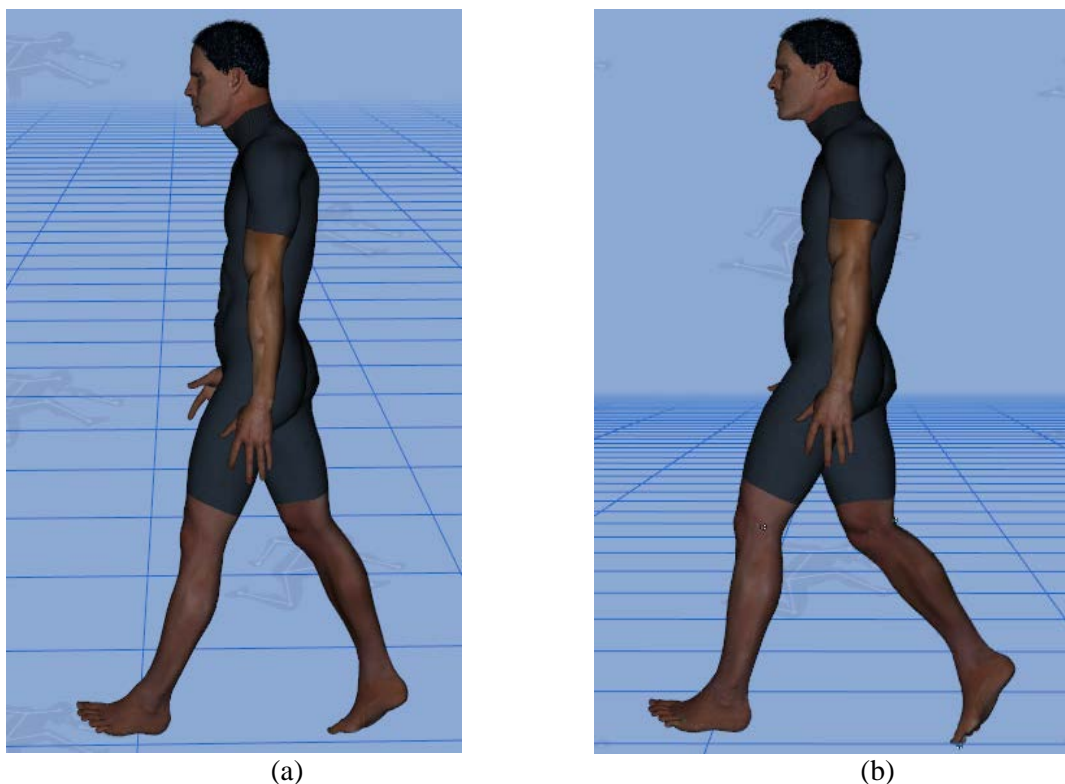


Figure 4 – Effect of scaling on Santos's motion: (a) without scaling and (b) with scaling based on subject height.

The next step in the motion-capture process, after unifying the skeletal models in Virtual 3D and Santos, was to use inverse kinematic software (IK code) to calculate the joint angles that will be used in animating Santos. Data processing through IK revealed inconsistency associated with the location of joint centers between the Santos biomechanical model and Virtual 3D. To correct this, Anatomical Hard Points (AHP), which are a more accurate representation of the location of the joint centers of the human subjects, were created inside the Santos biomechanical model. Figure 5 shows a case where the AHP was created for the knee joint to represent a more accurate knee joint center. Figure 5a shows Santos's knee flexion before adding the AHP, while Figure 5b shows Santos's knee flexion after adding the AHP. Figure 5b shows a knee flexion that is closer to that of the human subject. Figure 5c provides a close look at the AHP on Santos knee.

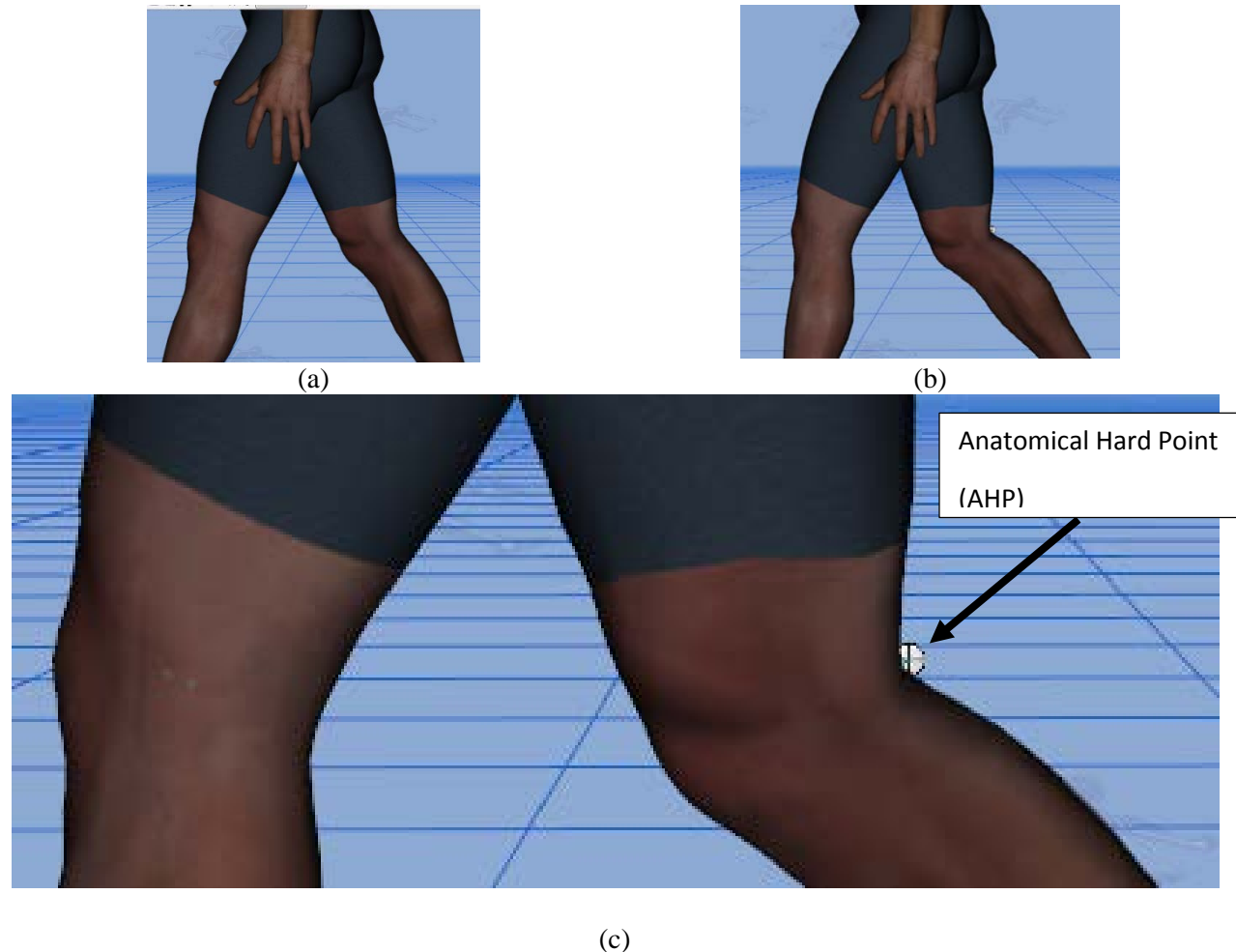


Figure 5 – Effect of the addition of Anatomical Hard Points (AHP) on Santos's motion: (a) without AHP, (b) with AHP, and (c) close-up of where AHP was added.

Gait Deviation Ratings

We have developed an assessment to examine general issues related to the ability of the user to observe differences in the walking pattern. We have created a module to assess Visual Sensitivity - Module 1. We have also generated two modules to train individuals to distinguish gait deviations:

Observational Gait Analysis: Module 1 - Trunk Motion and Observational Gait Analysis: Module 2 - Lower Limb Motion.

As a result of pilot testing during the first stage of this project, modifications were undertaken in an attempt to address issues of validity, user interface, and user compliance. The major change that was implemented was developing and incorporating a user interface that enabled the user to train strictly within the visual realm. Using the Manipulation tool, users are able to represent their observations of a particular event during the gait cycle by manipulating the avatar image. These manipulations are accomplished in the context of reinforcing what is the more ideal position and relating deviations in the observed gait to this ideal depiction.

The current version of the APGTT has four modules:

1. Pre-Test Module – used to determine the baseline observational skills of the user to detect deviations in the sagittal and frontal planes.
2. Training Module – used to hone the observational skills of the user to detect non-specific gait deviations at four critical times in the gait cycle by providing immediate feedback on results.
3. Post-Test Module – used to determine the effectiveness of the training tool to improve the observational skills of the user.
4. Prosthetic Training Module –used to examine amputee-specific gait deviations and acknowledge possible underlying etiologies.

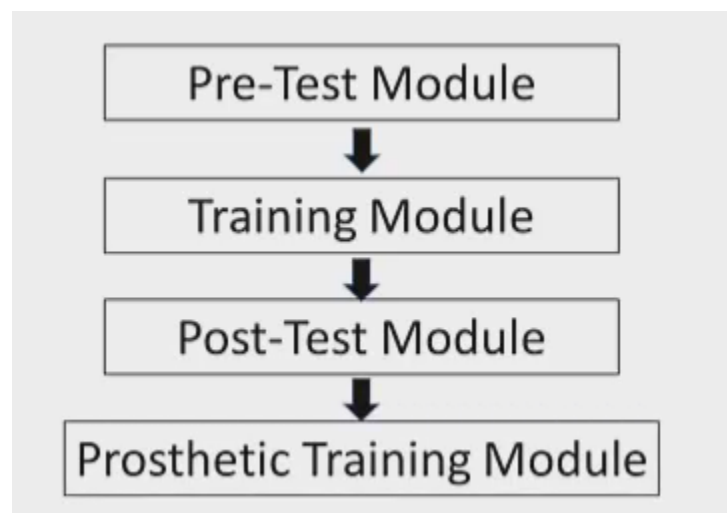


Figure 6 – Four modules define the progression through the Advanced Prosthetic Gait Training Tool.

PRE/POST-TEST MODULE:

The Pre/Post-Test Module asks users to assess video representations of deviant gait patterns. They are asked to document their observations of specific events during the walking cycle by observing the motion in the sagittal and frontal planes. For each event, they are asked specific questions about the

pattern of walking, with emphasis on one lower limb. Figure 7 shows a sample question assigned to users as they navigate the module.

For the **sagittal plane**, questions are focused on five events: (1) initial contact; (2) loading response; (3) mid-stance; (4) stance-to-swing transition; and (5) mid-swing.

For the **frontal plane** questions are focused on four events: (1) loading response; (2) mid-stance; (3) terminal stance; and (4) mid-swing.

The questions are presented in a way that enables the determination of three aspects of the user's response:

1. The ability to detect a less-than-ideal pattern by selecting any option other than "Close to Ideal."
2. The ability to correctly determine the direction of the deviation by selecting an option on either side of "Close to Ideal," based on two descriptors used to define the possible deviations.
3. The confidence the user has in detecting the deviation by selecting "Possibly," "Probably," or "Definitely."

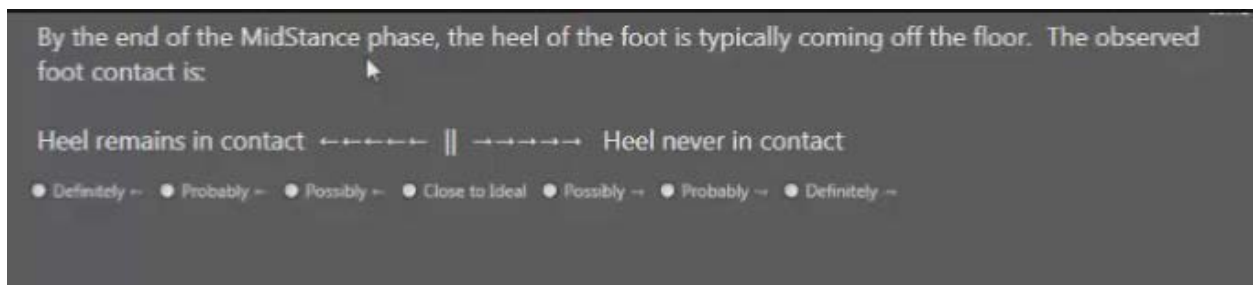


Figure 7 – Sample question in a Pre/Post-Test Module.

TRAINING MODULE

The Training Module sustains a focus on the visual environment by asking users to manipulate a static image of the Santos avatar to represent their perception of what they observe at particular events while watching a Santos video representing a gait deviation. The mode of operation of the manipulation tool is presented in Figure 8. In the sagittal view, the Manipulation tool has four "hot buttons" for adjusting angular changes in the hip, knee, ankle, and forefoot. Double-clicking on any of these hot buttons allows the user to adjust the position of the lower limb joints by left-clicking the mouse and moving it on the screen. In addition, using the keyboard to enter Shift+R allows adjustment of the trunk.

In a similar way, the frontal view of the Manipulation tool has three hot buttons that allow the user to adjust the trunk, hip, and ankle.

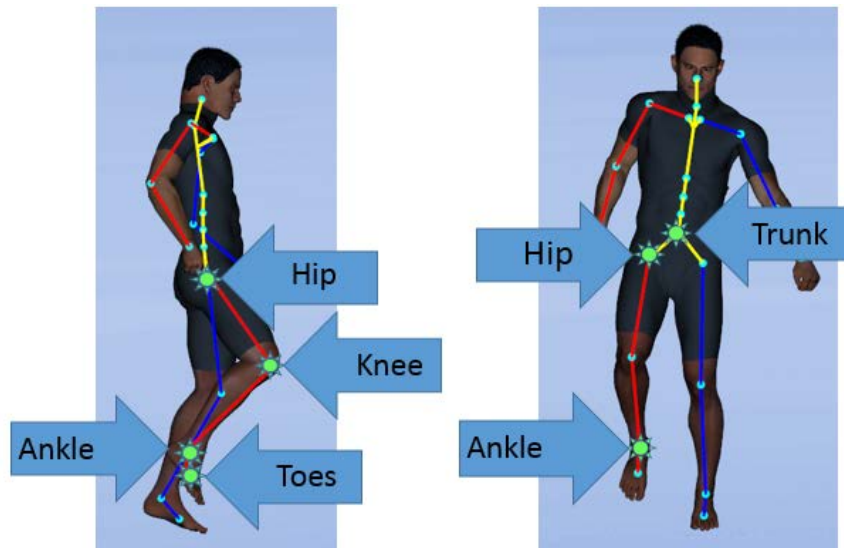


Figure 8 – Manipulation tool with hot buttons emphasized. Double-clicking on any of these buttons enables adjusting the position of the avatar identified for the sagittal view (left) and frontal view (right). Shift+R can be used to adjust the trunk in the sagittal view.

When users open the Training Module, they are asked to document their observation of the movement pattern at a particular event (for example, loading response).

They see three images (as shown in Figure 9):

- A movie showing the Santos avatar walking with a deviant walking pattern.
- A static image of what the “close-to-ideal” position is at the event being considered.
- The Manipulation tool.

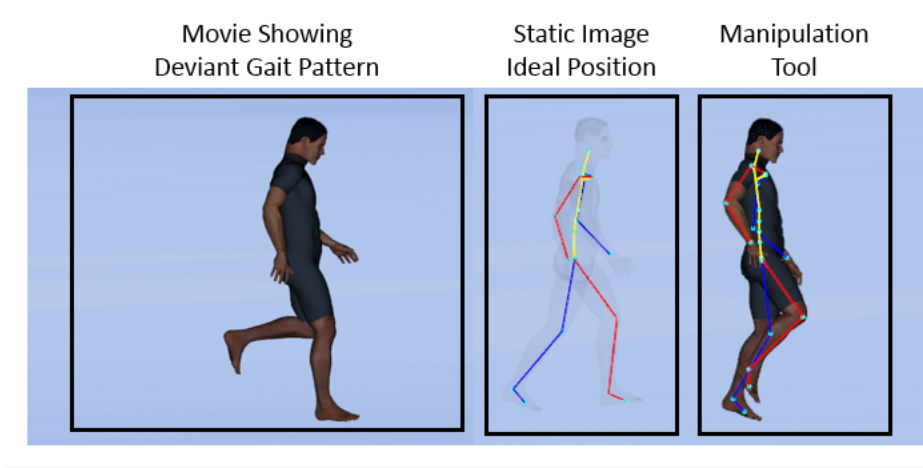


Figure 9 – Screen requiring users to manipulate avatar image to represent their observation.

Users are asked to adjust the Manipulation tool to a position that is close to what they are observing in the movie at this event. Once users have completed the manipulation of the avatar, they will submit their answer.

The next screen (shown in Figure 10) provides feedback to the users on their ability to observe the avatar at a particular event. Three images are displayed to the user:

- The same movie, showing a deviant walking pattern.
- A static image, taken from the movie, showing the actual position of the avatar at the particular event.
- The position the user judged the avatar to be in at the particular event, based on the Manipulation tool .

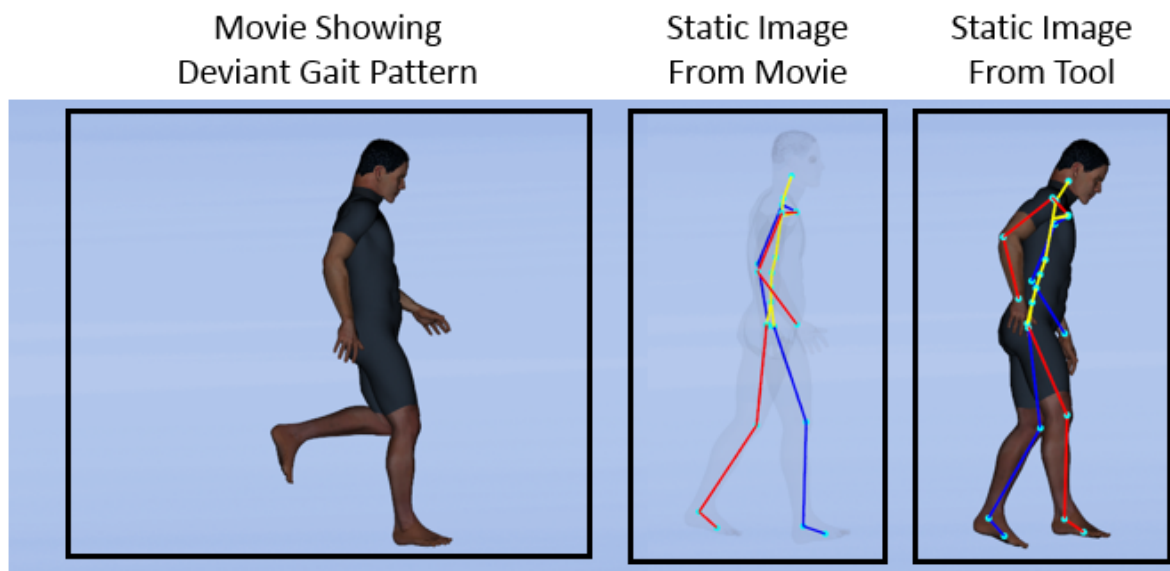


Figure 10 – Screen providing user feedback on how their manipulation matched the actual position occurring in the movie at the particular event.

In the sagittal plane, this process is repeated for five critical events of the gait cycle: (1) initial contact, (2) loading response, (3) mid-stance, (4) stance-swing transition, and (5) mid-swing.

In a similar way, users can manipulate the position of the image in the frontal plane to document their observation of the avatar in the movie. In the frontal plane, this process is repeated for four critical events of the gait cycle: (1) loading response, (2) mid-stance, (3) terminal stance, and (4) mid-swing.

While using the Training Module, users can select from a library of different deviant gait patterns, representing either the sagittal or frontal view, and repeat the viewing of any gait videos as often as desired.

Once the users believe they have improved their observational skills, they will be asked to take the Post-Test Module. This module duplicates the Pre-Test Module, but with a different order of the same video clips.

PROSTHETIC TRAINING MODULE

The Prosthetic Training Module applies the users' observational gait analysis skills to the understanding of gait deviations seen in individuals with lower-limb amputations. Videos of the Santos avatar are used to represent amputees' deviant gait patterns, as shown in Figure 11. The users are able to document their observations in the sagittal and frontal views.



Figure 11 – Image from movie representing amputee gait pattern.

In addition to feedback on their observational abilities, users are also provided information on possible etiologies, such as lateral trunk bend, gluteus medius weakness, socket aligned in abduction, decreased support of lateral socket wall, lateral-distal femoral discomfort, wide base of support, and leg-length discrepancy.

Prosthetic Gait Software

The functionality and visual appeal of the Prosthetic Gait software has improved significantly over the past year. The layout and usage of the software has been developed into a more intuitive and user-friendly format. From a quiz-developer standpoint, more options have been introduced and motion capture has been improved. From an end-user standpoint, navigation has been vastly improved and several bugs have been addressed. The software has been designed as modular and expandable so future enhancements are easy. A general quiz developer can include more clinical conditions and corresponding training and evaluation components without ever needing to change the code. Most quiz-developer-related functions are treated as dynamic data using either folder structures or a scripting interface based on Extensible Markup Language (XML).

The software, thus, treats a quiz developer as a user too. Hence, there are two different components of the Prosthetic Gait software depending on the user: (1) quiz developer and (2) clinical end user. The functionality corresponding to each of these components is discussed below.

QUIZ DEVELOPER

The Prosthetic Gait software works by reading an XML file, iterating through each of its nodes, and handling a user's input. This XML file is essentially a quiz that can be broken down into three main subtypes of quizzes: the pre-test phase, training phase, and post-test phase. In addition, each quiz type can have a number of different questions with various options and settings. All of this functionality is fully customizable, and the quiz developers have full flexibility to configure the quiz as per their needs.

The structure of the XML nodes is as follows:

Root: Single outermost root containing everything

Test: Each test node contains all of the information for a quiz with a question child node representing each question

- Attributes:
 - **Phase** = "pre," "training," or "post" – indicates the quiz phase.
 - **NavigationControl** = "true" or "false" – indicates whether the user can access previously answered questions.
 - **Feedback** = "true" or "false" – indicates whether the feedback will be given after each question is answered.
 - **Timer** = "{any floating number}" – indicates how long the user should take to complete this testing phase in minutes; e.g., 2.5 is 2 minutes and 30 seconds.
 - **IdealMocapFilePath** = the motion capture file path for the ideal "ghost" avatar.
- Child Nodes:
 - **Introduction** – Adds the intro page to the beginning of each testing phase
 - Attributes:
 - **AutoPlayOn** = "true" or "false" – indicates whether a motion capture file should be auto-played on Santos during this question. Motion would play first in the frontal plane and then in the sagittal plane.
 - **Opacity** = "full", "half", or "none" – indicates the opacity with which Santos is viewed.
 - **Skeleton** = "true" or "false" – indicates whether Santos's skeleton is visible or not.

- **Introduction** nodes:
 - **Title** content: {string} – the title to each phase. Appears in bigger text at the top of the page.
 - **Instructions** content: {string} – the paragraph of instructions to include. Type it exactly as you want it to appear.
 - **Images** – composed of ‘Image’ child nodes, the images that are to be shown on the feedback page.
 - **Image** attributes:
 - **Title** = “{string}” – the title to be shown below each image.
 - **Image** content: {string} – the file path of the image.
 - **View** – indicates whether Santos/ Motion capture should play on a separate video.
 - **View** attributes:
 - **Mode** = “Interactive,” “Video,” or “VideoInteractive.”
 - **VideoFilePath** = “{string}” – the path of the video to be played. Only necessary to include if in video mode.
 - **MocapFilePath** = “{File path}” – the path of the motion capture file that should be auto-played.
- **Question**
 - **Attributes:**
 - **AutoPlayOn** = “true” or “false” – indicates whether a motion capture file should be auto-played on Santos during this question. Motion would play first in the frontal plane and then in the sagittal plane. If true, it should include the **MoCapFilePath**, as well.
 - **Plane** = “frontal” or “sagittal” – indicates the only plane in which the motion will auto-play during the feedback page. If not included, default is first in the frontal plane and then in the sagittal plane like normal auto-play.
 - **Zoom** = “lower” or “upper” – indicates whether the camera should zoom into the lower or upper body during auto-play. If not included, it is full-body view.
 - **Checklist** = “true” or “false” – indicates whether the question format will be a checklist. Default (no attribute) is false, meaning a multiple-choice-format question.
 - **Layout** = “horizontal” or “vertical” – indicates whether the options should appear stacked horizontally or vertically. If not included, it is vertical by default.
 - **Opacity** = “full,” “half,” or “none” – indicates the opacity with which Santos is viewed.
 - **ManipulationOn** = “true” or “false” – indicates whether the user should be able to manipulate the right leg joints of Santos. If “true,” include **ManipulationJointData**, **Plane**, and **MocapFilePath**, as well.
 - **Child Nodes:**
 - **Description** content: {string} – the title to each question.

- **Images** – composed of ‘**Image**’ child nodes, the images that are to be shown on the feedback page.
 - **Image** attributes:
 - **Title** = “{string}” – the title to be shown below each image.
 - **Image** content: {string} – the file path of the image.
- **Options** – composed of ‘**Option**’ child nodes, the options to the question.
 - **Option** attributes:
 - **Answer** = “true” – indicates the correct answer to the question, simply don’t include for an incorrect answer.
 - **Option** content: {string} – the option’s text.
- **View** – indicates whether Santos/ motion capture should play on a separate video.
 - **View** attributes:
 - **Mode** = “Interactive”, “Video”, or “VideoInteractive.”
 - **VideoFilePath** = “{string}” – the path of the video to be played. Only necessary to include if in video mode.
 - **MocapFilePath** = “{File path}” – the path of the motion capture file that should be auto-played.
- **Additional Question** – Adds additional parts to a question. Can include a **Layout** attribute and **Description** and **Options** nodes just like in a **Question**.
- **ManipulationJointData** – essential to include if **ManipulationOn** is true.
 - **ManipulationJointData** attributes:
 - **MocapFrame** = “{any integer value}” – the frame of the motion capture file for this question to be frozen during manipulation.
 - **IdealMocapFrame** = “{any integer value}” – the frame of the ideal motion capture file for this question to be frozen on the “ghost” avatar during manipulation.
 - **ToeAngle** = “{any floating number}” – the correct angle of the right toe at this motion capture frame.
 - **AnkleAngle** = “{any floating number}” – the correct angle of the right ankle at this motion capture frame.
 - **KneeAngle** = “{any floating number}” – the correct angle of the right knee at this motion capture frame.
 - **HipAngle** = “{any floating number}” – the correct angle of the right hip at this motion capture frame.
 - **TrunkAngle** = “{any floating number}” – the correct angle of the trunk at this motion capture frame.
 - **ToeOffset** = “{any floating number}” – the number to be subtracted from the output value of the toe joint angle.
 - **AnkleOffset** = “{any floating number}” – the number to be subtracted from the output value of the ankle joint angle.

- **KneeOffset** = “{any floating number}” – the number to be subtracted from the output value of the knee joint angle.
- **HipOffset** = “{any floating number}” – the number to be subtracted from the output value of the hip joint angle.
- **TrunkOffset** = “{any floating number}” – the number to be subtracted from the output value of the trunk angle.

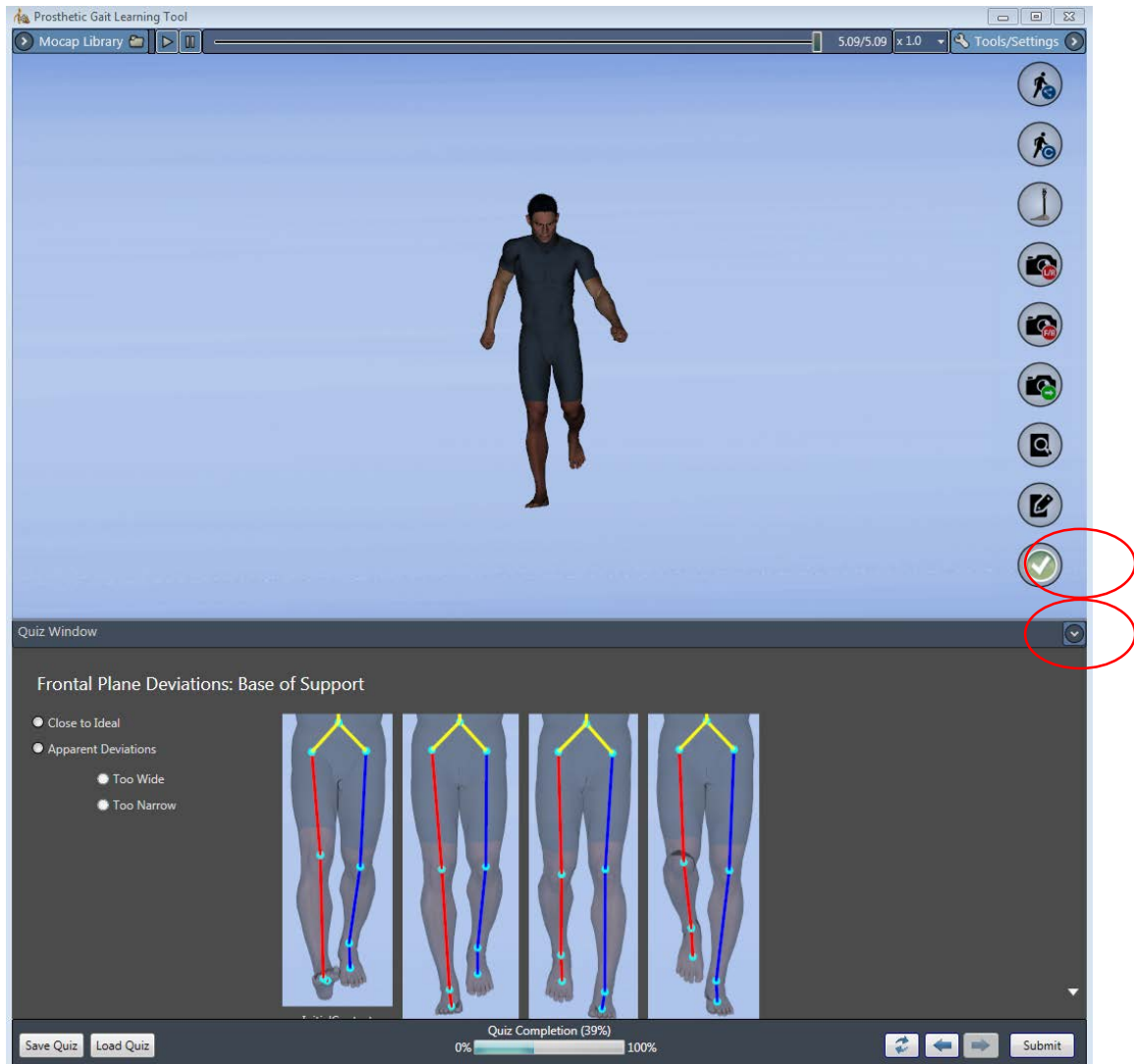


Figure 12 – The Motion capture Offsets and Gait Phase options (circled) are tools that will not be available to end users.

Once an XML file has been created, it should be named ProGaitQuiz.xml and placed in the Resources/Data folder. The correct motion-capture files should be placed in the Data folder as well. The Resources/Data/ProstheticGait folder is where quiz developers can populate the motion-capture library for their quiz.

It's important to note that if there is any need for joint offsets in a certain motion capture file, an XML file of the same name as the motion capture file should be placed in this folder. If no such file is present, default joint offsets will be used.

There is also additional functionality that will be available to quiz developers that will not be present for end users. The two toolbar options shown in Figure 12 (Motion capture Offsets and Gait Phase) will not be available to end users.

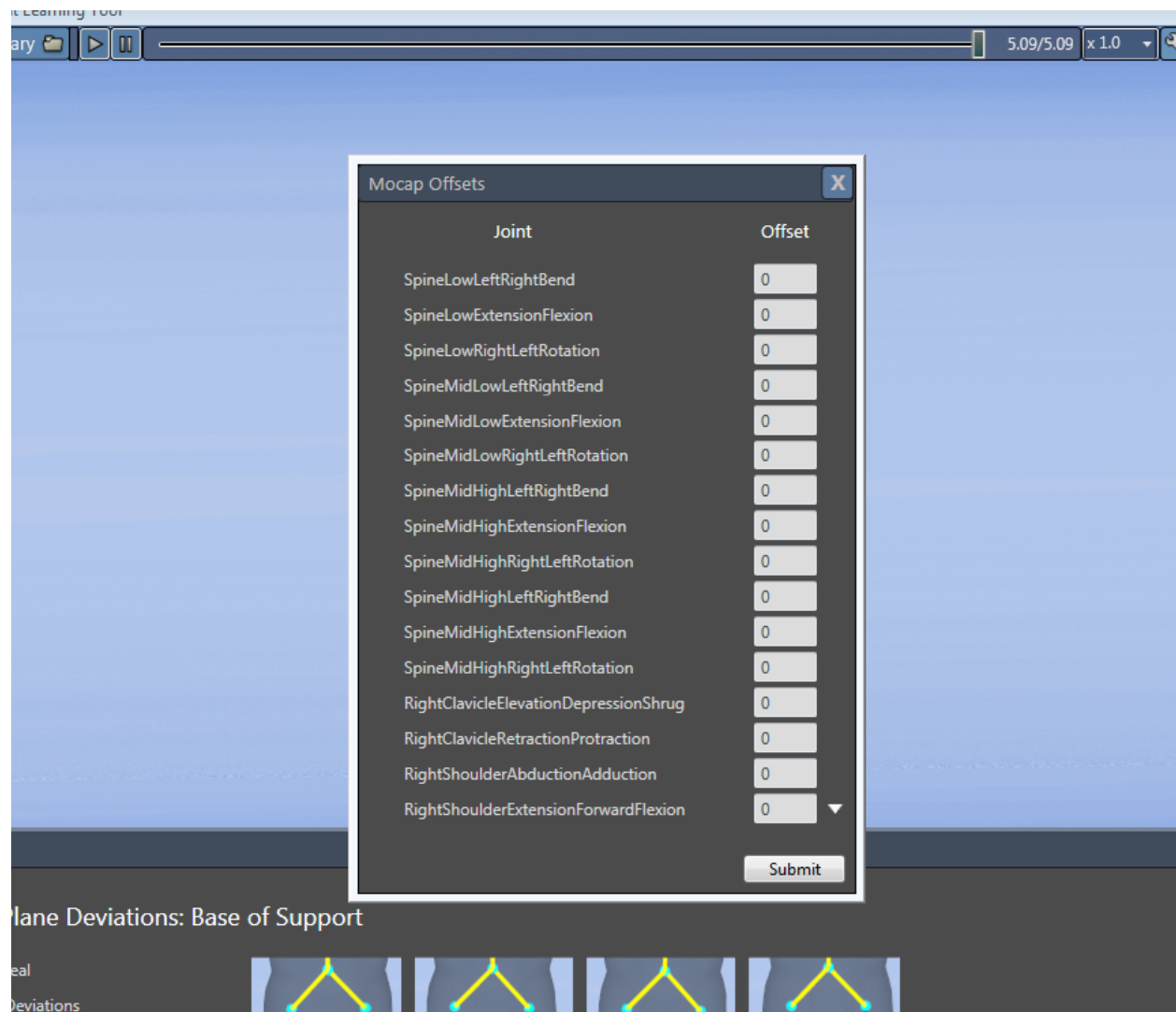


Figure 13: The Motion capture Offsets window lets a quiz developer enter values for each joint and see the output on the current motion capture file.

The Motion capture Offsets window (Figure 13) allows the quiz developer to manipulate the current motion capture file's joint offsets. This is especially useful when trying to determine if a certain offset value looks more correct than another.

The Gait Phase window (Figure 14) analyzes the current motion capture file and assesses the motion of the avatar's gait. If there is an abnormal gait, then a possible diagnosis may be given.

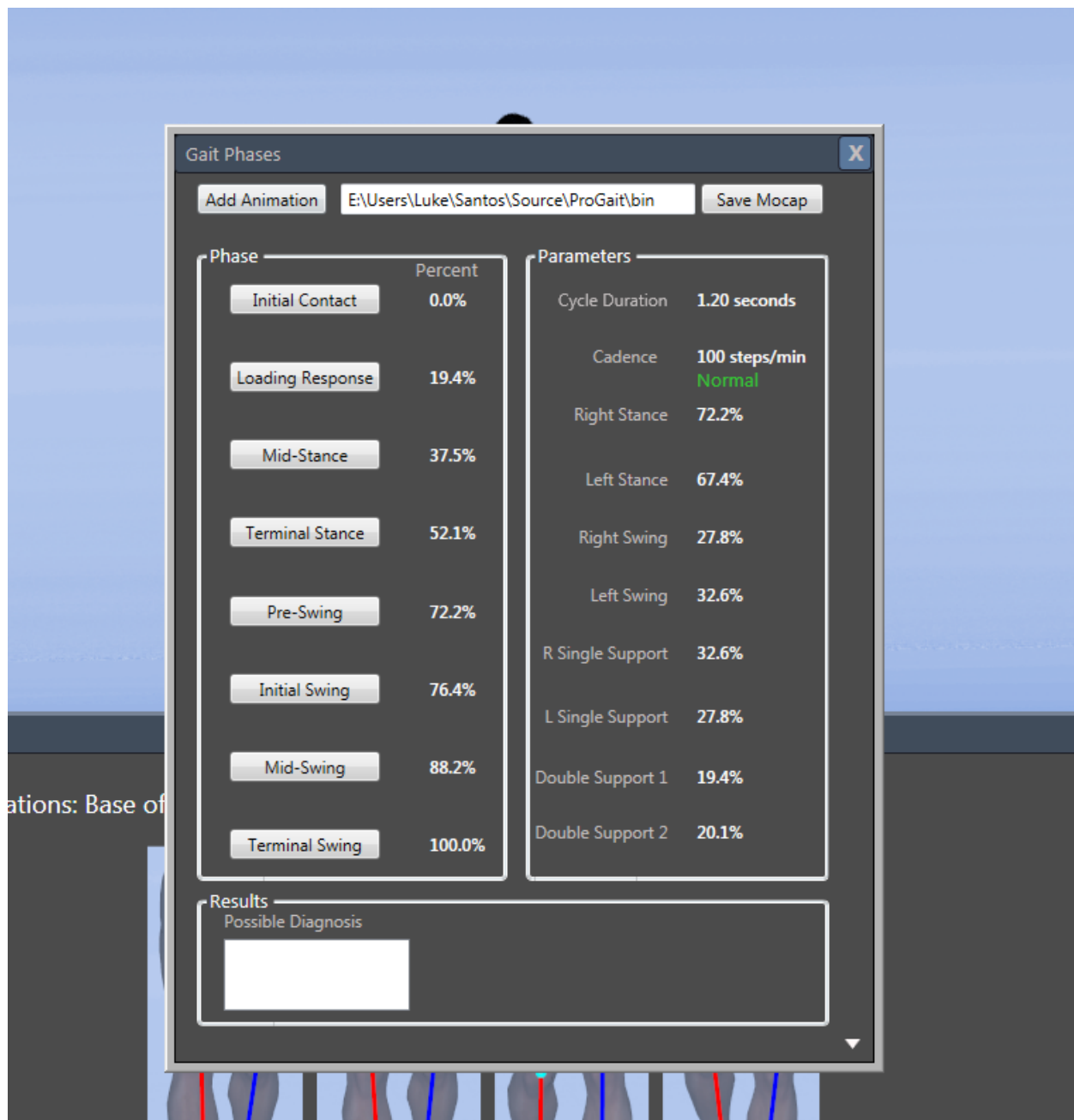


Figure 14: The Gait Phase window analyzes the current motion capture file and gives an assessment of the motion's gait.

End User

Once a quiz developer has created a quiz with the appropriate XML file and populated the Motion capture library, the end user will be ready to take the quiz and test his or her knowledge.

The flow of the software and the functionality available to the user will depend on how the quiz developer has set up the phases of the quiz. In the pre-test portion of the quiz, the user will most likely be timed and have to answer each question in order. The functionality available to the user is limited.

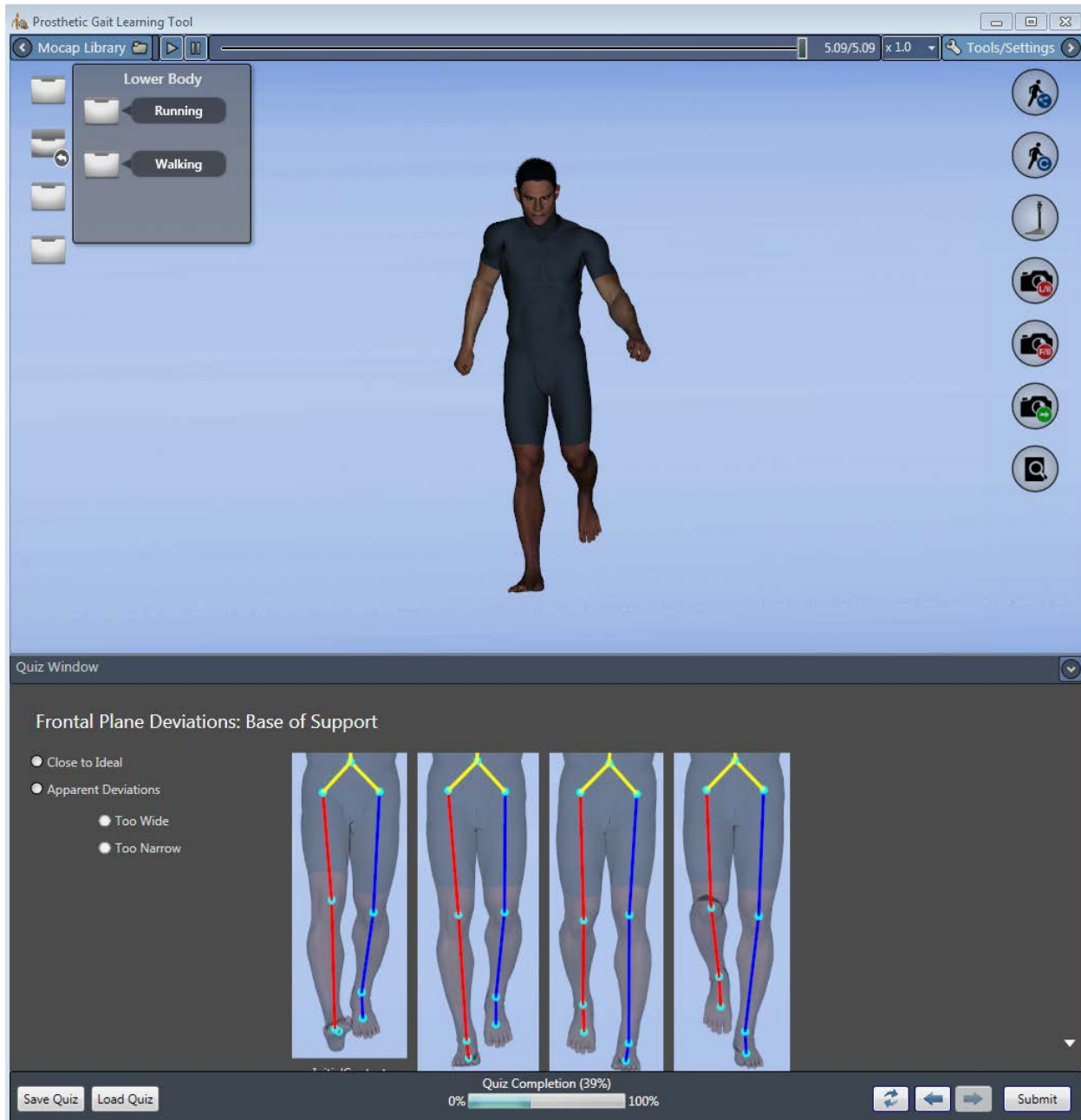


Figure 15: The end user can access additional functions during the training phase of the quiz.

Camera navigation will be available in all phases of the quiz. By clicking and dragging the left mouse button, the user can rotate the avatar. By clicking and dragging the right mouse button, the user can zoom in or out. Pausing, playing, and changing the speed of the motion capture are all functions available to the user in all phases of the quiz. Refreshing the question and loading a different quiz are also functions available in all phases of the quiz.

The post-test phase is the same as the pre-test phase in terms of the user's functionality being limited. However, the Save button is not available in the post phase of the quiz.

The training phase (Figure 15) of the quiz is where the user's restrictions are lifted.

By clicking the Motion capture library arrow in the top left corner, folders containing motion capture files slide into view. Tooltips containing each folder's category can be seen by hovering the mouse over each folder. The folders are currently organized into three categories: Control, Lower Body, and Upper Body. Opening a folder displays either the sub-folders inside of each category, if any exist, or the motion-capture files. For instance, if the Lower Body folder is clicked, two more folders (Running and Walking) pop up. Selecting either of these folders brings up the corresponding motion capture files associated with lower-body gait issues. The avatar is loaded with the appropriate data upon clicking a specific motion file. After selecting a new motion capture file, an icon is displayed on the respective file to enhance ease of user navigation within the folders.

Motion capture files can be played on the avatar through the use of the playback tools. The toolbar consists of a play button, pause button, playback slider, running time, and a play speed dropdown button. The playback slider allows for the user to manually select a frame of motion, and the time updates with sliding as well. The playback speed dropdown can be used to view motion at various speeds (x2.0, x1.0, x0.75, x0.5, x0.25).

Additional tools and settings can also slide in and out of view using the arrow in the top right corner. Tooltips display the capabilities of the buttons, which include: Show/Hide Skeleton, Show/Hide Control Avatar, Show/Hide Prosthetic, Left/Right View, Front/Back View, Camera Follow On/Off, and Lower/Upper Zoom.

Clicking the Show/Hide Skeleton button toggles between an almost transparent avatar with line skeleton, a fully opaque avatar with no line skeleton, and the default 50% opacity avatar with line skeleton. The color scheme of the line skeleton has been modified to match the online quiz developed by OGAL.

The Show/Hide Control Avatar button will add or remove a fully opaque avatar with no line skeleton next to the current avatar. The avatar produced by this button will always play the control motion capture file.

The user can toggle between the regular Santos avatar and a new avatar featuring a prosthetic leg by clicking the Show/Hide Prosthetic button. The line skeleton and all other functionalities can still be applied to the avatar with the prosthetic leg.

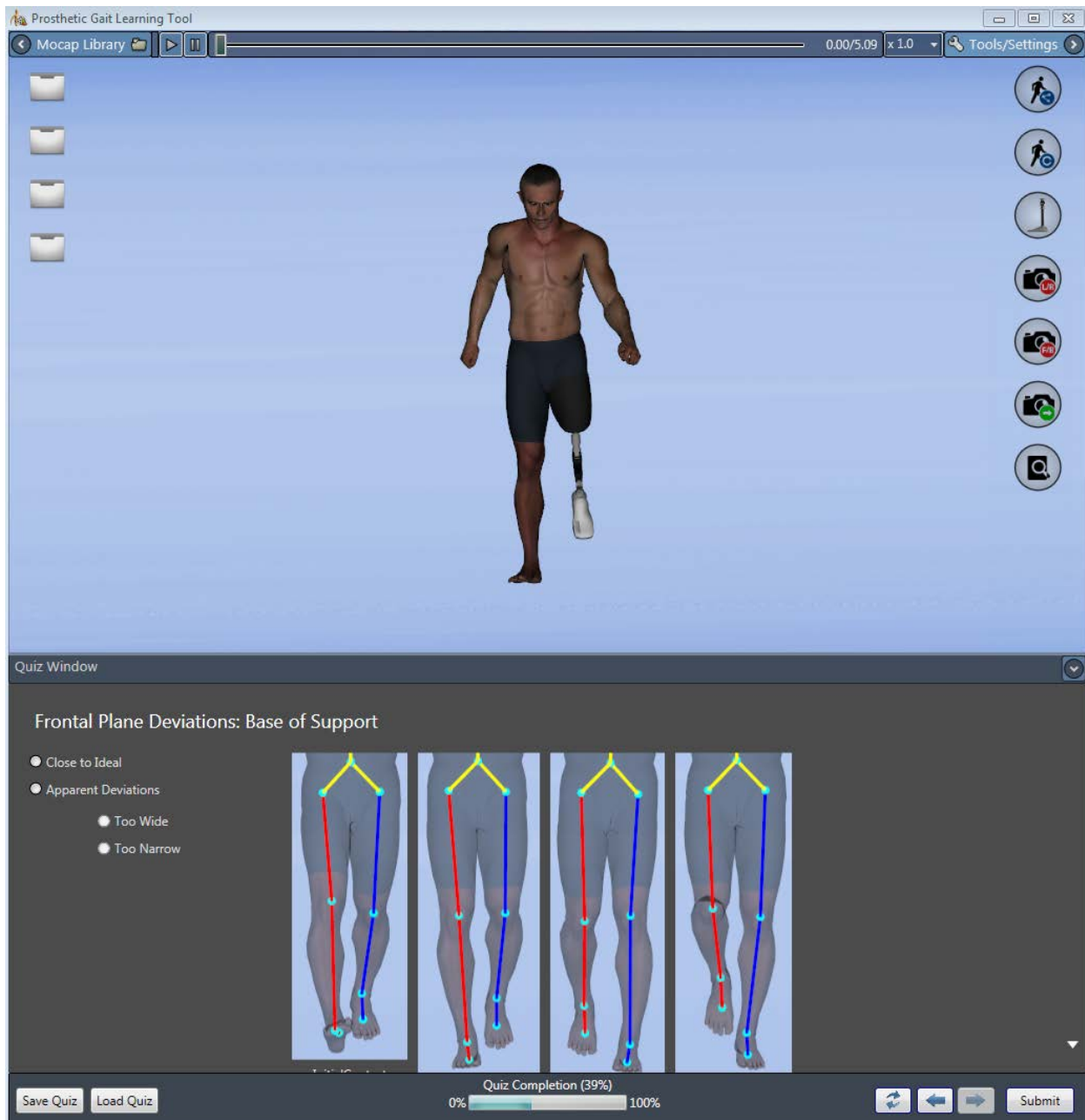


Figure 16: Santos with a prosthetic leg.

The Left/Right and Front/Back Camera View buttons will display the avatar(s) facing the corresponding direction. The Camera Follow On/Off button can be clicked to hold the camera stationary or fix it to follow the main avatar. The icon will change colors (green for follow on, blue for follow off) when clicked. When the camera is off follow mode, panning of the camera becomes available by clicking the middle mouse button. These functions are all disabled, however, when auto playing of the motion capture is still running.

The last button, Lower/Upper Zoom (Figure 17), offers the option of analyzing the avatar's gait when zoomed in on the lower body and the upper body. When this button is clicked, the zoom will toggle between lower zoom, upper zoom, and no zoom.



Figure 17: Santos with his zoom set to lower.

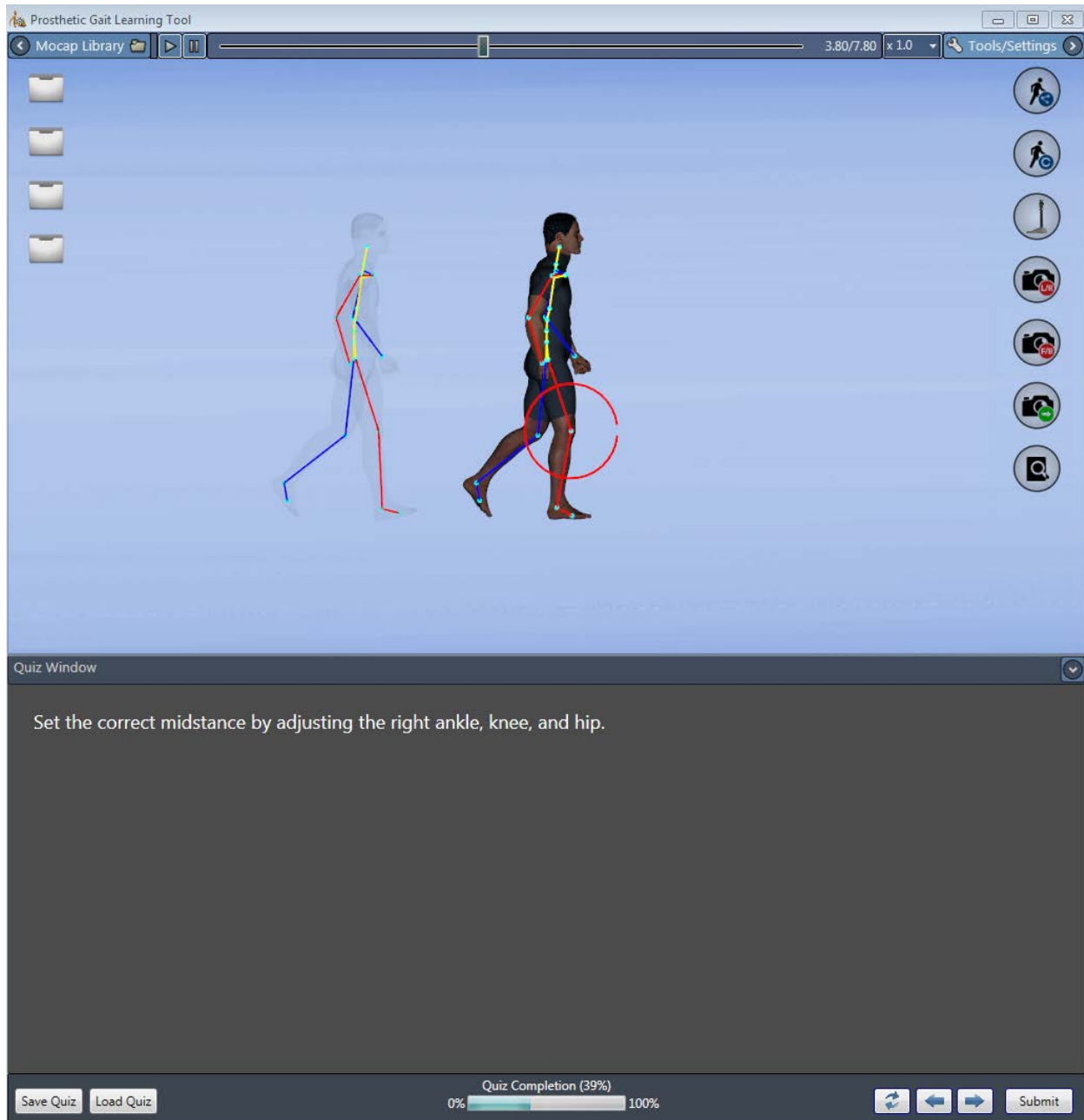


Figure 18: Santos with his knee joint selected.

Depending on how the quiz developer set up the training portion of the quiz, some questions may have the option to manually manipulate Santos's joints. These questions involve starting with a control Santos, and the user is then asked to manipulate the avatar in a way to replicate a desired gait. Feedback is shown to verify the correct answer.

When the right hip, knee, ankle, or toe joint is clicked, a degree of rotation will become available for the joint. Dragging the mouse while a joint has been selected will manipulate the joint.

Manipulating the avatar's trunk is a little different. In the sagittal plane, typing Shift+R selects the avatar's 'trunk,' and it can be manipulated with a mouse drag. In the frontal plane, this trunk joint is at the base of the avatar's spine and can be selected just as any other joint would be.

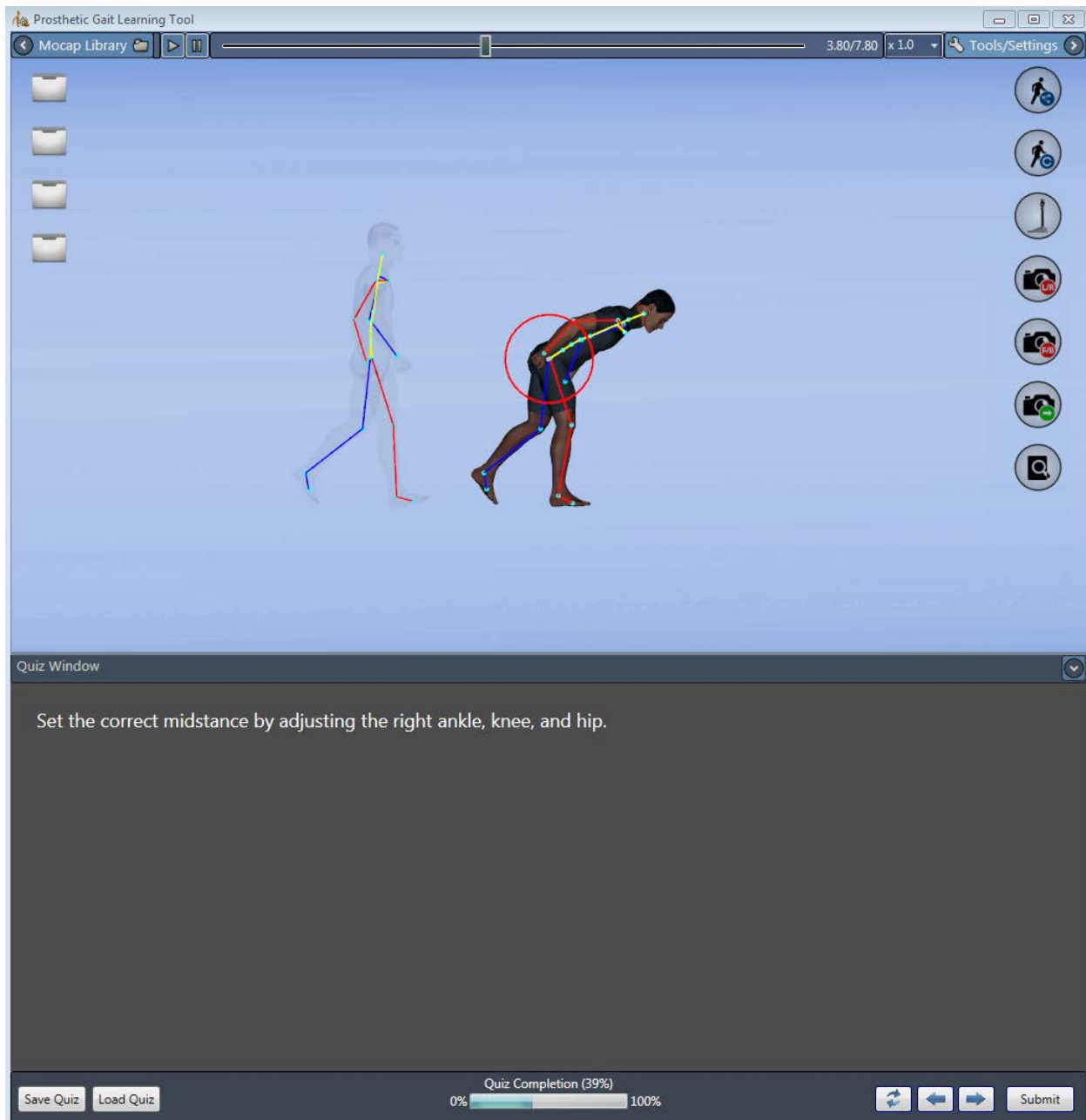


Figure 19: Santos with his trunk manipulated significantly.

Discussion and Conclusion

For the most part, the end user's functionality is very straightforward and has a low learning curve. It would not take a user much more than a few hours to learn the operation of this software, and it is this simplicity that makes this software so viable.

A quiz developer would need a tighter grasp on how the motion captures are made or processed and would need a working knowledge of XML structure. It is also assumed that the quiz developer would know many of the joint naming conventions and how to use tools such as the Gait Phase window. It is safe to say that there is quite a steep learning curve for quiz developers in comparison to end users. However, this was anticipated during creation of the software.

Pending securing further funding for the project, further testing of the Advanced Prosthetic Gait Training Tool is currently being planned and will be carried out in 2016.

